ECONOMIC IMPACTS OF CLIMATE CHANGE ON MAIZE PRODUCTION IN THE SUB-HUMID AND SEMI ARID AREAS OF TANZANIA

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ABSTRACT

Climate change is the cause of most weather related externalities.Its effectsare more evident on the environment, food security, human health, human settlements, economic activities, natural resources and physical infrastructure. This study assessed the economic impacts of climate change with a special focus on maize production. It examined the role of socioeconomic and biophysical characteristics in determining maize net revenue, the marginal impact of changes in climate variables and projected climate change impact on net revenue from maize enterprise due to future changes in climate in the sub-humid and semi-arid areas of Tanzania. The study utilized cross-sectional household data collected by the National Bureau of Statistics under its National Panel Survey in 2011/2012 from which 323 households were randomly sampled. Both descriptive and econometric methods were used to analyze the data. The Ricardian model was employed to assess the impact of climate change on maize production and in the model net revenue per hectare was regressed against a set of climate variables, socio-economic and biophysical variables using a two stage least square estimation method so as to address the problem of correlation between the dependent variable error term and the independent variables for the sub humid and semi-arid areas and across all farms. Results from the analysisindicated that household size and education of the household headpositivelyimpacted net farm return from maize production. Also it revealed that temperature and rainfall ($p < 0.01$) will negatively impact net revenue. Basing on the CMIP5 for Tanzania using the Mid-Century Representative Concentration Pathway (RCP) 8.5 the predicted future climate change will adversely impact net revenue from maize production in the sub-humid and semi-arid areas of Tanzania by the year 2050. Thereforeinvesting in new technologies and adequate extension information services are recommended from this study so as to increase farmers' adaptive capacity to reduce the impact of climate change on maize production.

DECLARATION

I, JOYCE KADADA VALERIAN, do hereby declareto the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

________________________ ____________________

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(MSc. Candidate)

The above declaration is confirmed

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Dr. K. D. S. Mutabazi Date

(Supervisor)

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DEDICATION

This dissertation is dedicated to my father, Professor V.C.K Silayo and my mother, Mrs. Dativa Patrice Silayo, whom together laid the foundation for my education.

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LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone models
CMIP5	Coupled Model Inter-comparison Project Phase 5
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GEF	Global Environment Facility
IPCC	Intergovernmental Panel on Climate Change
IV	Instrumental Variable
Kg	Kilograms
LGP	Length of Growing Period
NR	Net Revenue
NPS	National Panel Survey
NBS	National Bureau of Statistics
RCP	Representative Concentration Pathway
TMA	Tanzania Meteorological Agency
Tshs	Tanzanian Shillings
T/ha	Tons per hectare
VIF	Variance Inflation Factor

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Climate change is the cause of most weather related externalities being larger, more complex and more uncertain than any other environmental problems. Its effects are becoming more obvious as shown by more frequent and severe droughts, hurricanes, floods and storms which threaten the livelihoods of people in developing world. It affects agriculture, energy, health, human settlement, economic activities, natural resources and physical infrastructure (Kijazi, 2012). The causes and consequences of climate change are very diverse, and low income countries such as Tanzania who contribute least to climate change are most vulnerable to its effects (Tol, 2009).

The economy of Tanzania is mostly depending on the agricultural sector. Despite the country having a rich base of land and water resources and a favorable climate in many areas, Tanzanian agriculture is characterized by low productivity that contributes to persistent poverty. Agriculture accounts for 27% of GDP and 35% of the foreign currency and employs about 80% of the majority Tanzanians of whom being small scale farmers growing food crops (NBS, 2014).

The growth of the agricultural sector which remained at around 3% for a decade has varied across food crops, cash crops, livestock, forestry and hunting. Among the food crops, maize is the dominant and the most important crop for food security and agricultural economic growth followed by paddy, beans, cassava, sorghum and wheat (Pauw and Thurlow, 2010). Despite its importance maize total yield has been fluctuatingfrom one year to another due to factors such as shortage of rainfall.The increasing production in maize crop is attributed by the expansion in area under cultivation and the use of fertilizers especially following input subsidy program (Mbilinyi *et al.*, 2013).

In Tanzania, maizeis produced by smallholder farmers who depend on rain-fed agriculture. According to theTanzania Meteorological Agency (TMA), the current climate is predicted to change and there is growing evidence that climate change is already impacting and is expected to have impacts on maize production in Tanzania (Ahmed *et al.*, 2009 and Arndt *et al*., 2012).

Maize yields in the Northern zone of Tanzania are expected to increase substantially in the wet scenario, but decrease by similar amounts in the hot and dry scenarios and varied impacts are expected to occur across regions but within the same scenario, for example in the northern zone in Manyara region maize yields are projected to increase by 15 % in the wet scenario, but decline by 12 % in Tabora in the central zone (Arndt *et al*., 2012).

This study was therefore carried out in the sub-humid and semi-arid areas of Tanzania including Kilimanjaro, Tanga, Morogoro, Singida, Dodoma, Mbeya, Songea and Iringa regions so as to capture the impacts of the changing climate on maize production which is the primary food crop for most Tanzanians and hence important for national food security.

1.2 Problem Statement

Maize is the most important staple food in Tanzania cultivated on an average of two million hectares which is about 45% of the cultivated area in Tanzania (Kaliba *et al.*, 2000). The production of maize is rain-fed and on average is around 3-4 million tons a year in the country. According to Jéan (2003), maize productivity is a function of climate and soil that can be regarded as the yield potential of a certain area.

Maize crop requires warm weather and it is grown in areas where the mean daily temperature is between 16 to 19 ºC. Maize also requires the right amount of water mainly from the rain water under predominant rain-fed system. In the presence of rainfall and temperature stresses maize yields in Tanzania are likely to decrease by 14% and 23% by the year 2030 and 2050 respectively compared to the baseline year 2000, which implies a decline of about 1.1 m tons and 2.9 m tons by using an average simulated yield of 1.3 t/ha (Ahmed *et al*., 2009).

These changes in climate which in turn limit maize productivity imply less income to families which depend directly on maize farming as their source of food and income. The maize enterprise also serves as the means to feed their families, send children to school, provide for their family's health and invest in their farms in order to become economically stronger and more stable (Armstrong and Lumpkin, 2009).

Studies have been conducted on the climate change impacts. Arndt *et al*. (2012) estimated the impact of climate change on agricultural production in Tanzania whereby climate change was estimated to cause the decline in food security in Tanzania. Bezabih *et al*. (2010) examined the economic impacts of climate change on the overall growth of the economy of Tanzania and the effects of climate change were estimated for each sector in the economy without considering that changes in climate impact differently on the sub sectors in the economy. Moreover, Ahmed *et al*. (2009) examined the impact of climate change on crop production in Tanzania by using an analytical framework which allows the estimation of inter annual changes in grain productivity that can be attributed to only temperature and precipitation.Sanga *et al*. (2013) examined the impact of the changing climate on net revenue from maize and beans production and compatibility of adaptation strategies in Pangani River Basin.

Most addressed impacts of climate change on crop production (i.e. physical yields) are based on assessing the impact of climate change on agriculture as a whole, the crop sector and various strategies that farmers undertake to cope with climate change and suffer from measuring the incremental social cost and benefit associated with climatic changes. Due to this it is important to estimate the economic effects that are posed by climate change on agriculture particularly on maize production. Therefore, this studyaimed at assessing the economic impacts of climate change with a special focus on maize production while explicitly examining the role of socioeconomic and biophysical characteristics, the marginal impact of changes in climate variables and projected climate change impact on net revenue per hectare of maize crop due to future changes in temperature and precipitation. The study will inform the policy makers on the need to promote economically feasible adaptation actions to minimize the vulnerability of maize production and the farmers who directly depend on the crop.

1.3 Objectives of the Study

1.3.1 Overall objective

The overall objective of this study is to assess the economic impacts of climate change on smallholder maize producers in order to draw adaptation policies and actions.

1.3.2 Specific objectives

The specific objectives of the study are:

i. To analyze the relationship of income from maize production with biophysical and socioeconomic variables;
ii. To determine the marginal impact of temperature and rainfall on income from maize production; and
iii. To predict future climate changeimpacts on maize production under a mid-range emission scenario.

1.4 Hypotheses

i. There is no significant relationship between income from maize production and biophysical and socioeconomic variables,
ii. The marginal impact of climate change on net farm revenue from maize production is significantly positive,
iii. Maize productionis profitable under future mid-range emission scenario.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definitions of Key Concepts

2.1.1 Climate change and climate variability

Climate change refers to a long-term continuous change (increase or decrease) of average weather conditions or the range of weather. It occurs as a result of temperature variability due to greenhouse gases produced by human activities. IPCC (2007) defined climate change as any change in climate over time, whether due to natural variability or as a result of human activity. On the other hand climate variability is a year to year fluctuation of climate around normal or is the way climate fluctuates yearly above or below a long-term average value (Dinse, 2009).

2.1.2 Climate change adaptation

It refers to ability of people or the system to adjust to climate change in order to reduce its vulnerability and enhance the resilience to observed and anticipated impacts of climate change. IPCC (2007) defined adaptation as adjustment in natural or human systems to a new or changing environment and adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

2.2 Projected Climate over Tanzania

Tanzania's climate is influence by its location near equator, the impact of the Indian Ocean and the physiography in general. The climate ranges from tropical to temperate with altitudinal variation being responsible for extremes. Average temperature ranges between 17^0c and 27^0c over the entire region. According to meteorological data, monthly temperatures over the last thirty years are already showing an upward trend (NAPA, 2007).

OECD (2003) has carried out a detailed analysis of Tanzania's temperature using separate models (MAGICC/SCENGEN) and results from both models projected temperature rise of 2.2^{o}C by 2100, with higher increases (2.6^{o}C) in June, July and August and lower value (1.9 °C) for December, January and February.

Also the average precipitation is estimated to be 1 042mm over the entire nation, but the localized rainfall is complex since the country has two distinct regimes, bi-modal in northern Tanzania, with long rains between March and May also known as *Masika*and short rains between October and December also called *Vuli*. Another regime is a single rainfall between November and April in the South of the country. The MAGICC/SCENGEN analysis projects annual precipitation over the whole country to increase by 10% by 2100, although seasonal declines of 6% are projected for June, July and August, and increases of 16.7% for December, January and February. NAPA (2007) reported that the most recent and common rainfall trend in Tanzania has a greater variability in cycles.

2.3 Approaches Used to Study Economic Impact of Climate Change

In studying the economic impacts of climate change in relation to agriculture, two main types of economic impact assessment models can be employed: the economy wide models, also known as general equilibrium models and the partial equilibrium models. According to Sadoulet and De Janvry (1995) the general equilibrium models are analytical models which look at the economy as a complete system of interdependent components, while the partial equilibrium models are based on the analysis of part of the overall economy such as a single market or subset of markets or sector. The models assume no interaction among the sectors of the economy.

There are three partial equilibrium approaches used to study impacts of climate change on agriculture. These approaches are agro-economic models, agro-ecological zone models and the Ricardian cross-sectional models (Mendelsohn and Dinar, 1999).

2.3.1 Agro-economic models (crop simulation models)

The Agro-economic models make use of well-standardized crop models from carefully controlled experiments in which crops are grown in field or laboratory settings that simulate different climates and levels of carbon dioxide in order to estimate yield responses of a specific crop variety to certain climates and other variables (Adams *et al*., 1990, 1993, 1999; Easterling *et al*., 1993; Kaiser *et al*., 1993; Rosenzweig and Parry, 1994; Parry *et al*., 1999, 2004; Kumar and Parikh, 2001;Mano and Nhemachena, 2007).

To ensure that all different outcomes across experimental conditions can be assigned to the variables that are being investigated, no variability is allowed in farming methods. Moreover, the estimates of these models do not include the effect of farmer adaptation to changing climate conditions. The economic models are then used to predict aggregate crop outputs, prices and net revenue using the yields from the agronomic models which tend to overstate the damages of climate change to agricultural production (Mendelsohn and Dinar, 1999).

2.3.2 Agro-ecological zone (AEZ) models

This approach combines crop simulation models with land management decision analysis, while capturing the changes in agro-climatic resources. AEZ analysis categorizes existing lands by agro-ecological zones, which differ in the length of growing period and climate. This approach assigns crops to agro-ecological zones and yields are then predicted (FAO, 1996). The length of growing period is defined based on temperature, precipitation, soil characteristics and topography. The changes in the distribution of the crop zones along with climate change are traced in AEZ models.

Crop modeling and environmental matching procedures are used to identify crop-specific environmental limitations under various levels of inputs and management conditions, and provide estimates of the maximum agronomical attainable crop yields for a given unit of land. However, as the predicted potential attainable yields from AEZ models are often much larger than current actual yields, the models may overestimate the effects of autonomous adaptation. Cline (1996) observed that AEZ studies tend to attribute excessive benefits to the warming of cold high-latitude regions, thereby overstating global gains from climate changes.

2.3.3 Ricardian cross-sectional models

These models measure the relationship between net revenue from crops and climate using cross-sectional evidence (Kurukulasuriya *et al.*, 2006). The models explore the relationship between agricultural capacity which is measured by land value and climate variables which are usually temperature and precipitation based on statistical estimates from farm survey or country level data. They account for the direct impacts of climate change on yields of different crops as well as the indirect substitution of different inputs, introduction of different activities and other potential adaptations to different climates.

The most important advantage of these models is that they incorporate private adaptations, since farmers adapt to climate change to maximize profit by changing the crop mix, planting and harvesting dates and different agronomic practices.

Farmers'responses to adaptation involve costs, causing economic damages that are reflected in net revenue, and to fully account for the cost and benefit of adaptation the relevant dependent variable in the Ricardian approach is net revenue or land value induced by climate factors (Deressa, 2007).

Like any other approach, the Ricardian approach also has a criticism that it fails to control fully the impact of other variables that can explain the variation in farm incomes, since variability in farms is a result of many factors other than the effect of climate change. According to Mendelsohn (2000), Ricardian studies (Mendelsohn *et al.*, 1994; Kumar and Parikh, 1998) have tried to control for this problem through the inclusion of other variables such as soil quality, market access and solar radiation, but these effort have been hindered by lack of perfect measures of these variables. This is due to the fact that many of these factors may not be taken into account when assessing the impacts on farm revenues.

Cline (1996) pointed out another criticism of this approach that it assumes constant prices and in that it leads to bias in the welfare calculation. This cross sectional approach only measures the loss as producer surplus from climate change and ignores the price change that would occur if supply is changed and as a result it omits consumer surplus from the analysis causing damages to be underestimated and benefits to be overestimated. According to Kurukulasuriya and Rosenthal (2003), the over estimation and underestimation of benefits and damages respectively occur in all agro-economic models due to the difficult of predicting domestic price changes when changes in agricultural prices as a result of climate change are determined at the global level.

Mendelsohn and Tiwari(2000) argued that the Ricardian model does not take into account the fertilization effect of carbon dioxide concentrations (higher CO_2 concentration can enhance crop yield by increasing photosynthesis and allowing more efficient use of water) is another weakness of the model.

But despite the weaknesses the Ricardian model can be used to analyze the economic impact of climate change on agriculture by fully considering the adaptations and other farm-level management that farmers make to mitigate the harmful effects of the change in climate.

2.4 Review of Empirical Studies

Mano and Nhemachena (2007) assessed the economic impacts of climate change on agriculture in Zimbabwe by employing a Ricardian approach. Farm revenue was regressed against various climate, soil, hydrological and socio-economic variables to determine the factors that influence variability in net farm revenue. The study was based on data from a survey of 700 smallholder farming households interviewed across the country.

The empirical results from the study showed that climatic variables (temperature and precipitation) have significant effects on net farm revenues in Zimbabwe. In addition to the analysis of all farms, the study also analyzes the effects on dry land farms and farms with irrigation. The analyses indicate that net farm revenues are affected negatively by increases in temperature and positively by increases in precipitation. The results from sensitivity analysis suggested that agricultural production in Zimbabwe’s smallholder farming system is significantly constrained by climatic factors (high temperature and low rainfall). The elasticity results show that the changes in net revenue are high for dry land farming compared to farms with irrigation.

Another study by Kurukulasuriya *et al*.(2006) examined how farmers in 11 countries in Africa have adapted to existing climatic conditions. It then estimated the effects of predicted changes in climate while accounting for farmer adaptation that might occur by using a Ricardian approach.

The study results showed that African agriculture is particularly vulnerable to climate change and that even with adaptation; regional climate change is predicted to entail production losses of 19.9 % for Burkina Faso and 30.5 % for Nigerby 2050. By contrast, countries such as Ethiopia and South Africa are hardly affected whereby they will suffer productivity losses of only 1.3 % and 3 %, respectively. The study also confirmed the importance of water supplies as measured by runoff, which is being affected by both temperature and precipitation.

Moreover, Kassahun (2009) assessed the economic impact of climate change on crop farming activities in Nile basin of Ethiopia using the Ricardian model. The study was based on data generated from 20 districts over 975 farmers. Annual crop net revenue was regressed on climate and other variables. The regression results were then used to estimate the marginal impacts of the climate variables on crop net revenues and yielded different results for temperature and precipitation and also for irrigated and dry farmlands. The results from their analysis indicated that an annual increase of 1°C in temperature will have a positive impact on annual crop net revenues for irrigated farms, but a negative impact for dry land farms and farms that represent Nile basin of Ethiopia. However, marginal impact of increasing precipitation will increase crop net revenue for both irrigated and dry land farms. In addition, the study examines the impact of uniform climate scenarios on the crop net revenue.

Deressa (2007) measured the economic impact of climate change on Ethiopian agriculture and described farmer's adaptations to varying environmental factors by using a Ricardian approach. The study used data from 11 out of the country's18 agro-ecological zones. The survey used 1 000 farmers from 50 districts. Net revenue was regressed against climate, household, and soil variables and it showed that the variables have a significant impact on the farmers' net revenue per hectare.

The study also carried out a marginal impact analysis of increasing temperature and changing precipitation across four seasons. It examined the impact of uniform climate scenarios on farmers' net revenue per hectare. Also, it analyzed the net revenue impact of predicted climate scenarios from three models for the years 2050 and 2100.The results indicated that increasing temperature and decreasing precipitation are both damaging to Ethiopian agriculture although the analysis did not incorporate carbon fertilization effect, role of technology, or the change in prices for the future.

Another study by Gbetibouo and Hassan (2004) used a Ricardian model to measure the impact of climate change on South Africa's field crops and analyzed potential future impacts of further changes in the climate. A regression of farm net revenue on climate, soil and other socioeconomic variables was conducted to capture farmer-adapted responses to climate variations. The analysis was based on agricultural data for seven field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower and soybean), climate and edaphic data across 300 districts in South Africa. Results from the study indicated that production of field crops was sensitive to marginal changes in temperature as compared to changes in precipitation. Temperature rise positively affects net revenue whereas the effect of reduction in rainfall is negative. The study also highlighted the importance of season and location in dealing with climate change showing that the spatial distribution of climate change impact and consequently needed adaptations will not be uniform across the different agro-ecological regions of South Africa. Results from the climate change scenarios indicated thatthere is a need for shifting farming practices and patterns in different regions such as shifts in crop calendars and growing seasons, switching between crops to the possibility of complete disappearance of some field crops from some region.

Kurukulasuriya and Mendelsohn (2008) examined the impact of climate change on cropland in Africa. The study based on 11counties with over 9000 farmers administered as part of a Global Environment Facility (GEF) project. It used the Ricardian cross sectional approach to measure the relationship between net revenue from growing crops and climate. Net revenue was regressed against climate, water flow, soil and economic variables. Results showed that net revenue falls as precipitation falls or as temperature warms across all the surveyed farms. Elasticity of net revenue fall in temperature was found to be -1.3 implying that a 10% increase in temperature would lead to a 13 % decline in net revenue and elasticity of net revenue with respect to precipitation was found to be 0.4.

2.5 Theoretical Framework

The theoretical basis of the Ricardian model is rooted from a famous theory of ‘economic rents’ by David Ricardo because of his original observation that land rents would reflect the net productivity of farm land at a site under perfect competition. However, much of its application to climate-land value analysis comes from Mendelsohn *et al.* (1994) in measuring the economic impact of climate on land prices in the USA. The approach has been used to evaluate the contribution of environmental conditions to farm income and by regressing land value on a set of environmental inputs; the marginal contribution of each predictor to farm income can be measured.

The Ricardian model simply examines how climate in different places affects the net revenue or value of land and by directly measuring farm prices or revenues the Ricardian model accounts for the direct impacts of climate on yields of different crops as well as the indirect substitution of different inputs, introduction of different activities, and other potential adaptations by farmers to different climatesSeo *et al.* (2005). Therefore, this study employed the Ricardian model to examine the impact that climate change has on farmers' welfare.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Conceptual Framework

Studies on the impact of climate change on agriculture employ the Ricardian model in analyzingthe impact of climate change (Mendelsohn *et al*., 1994) while traditional studies have used the production function approach (Rosenzweig and Iglesias, 1998). The approach has been found to be attractive because it not only includes the direct effect of climate on productivity but also the adaptation response by farmers to local climate change. Farmers in maize production systems are aware of the issues regarding climate change and will often accredit changes in farm productivity to changes in rainfall patterns. But the nature of climate variation depends on farmers' perception about climate change and variability and these perceptions about climate change influence the way in which they adapt to changes in climate which is either by doing crop mix, changing management decision or changing of the planting and harvesting dates. Again the impacts of climate change on farmers' welfare are not only determined by the changes in rainfall and temperature but are also contributed by the biophysical and socio economic characteristics of a particular farmer and therefore combining all these together will give the impact of climate change on maize production measured by changes in farmers' welfare due to change in climatic conditions.

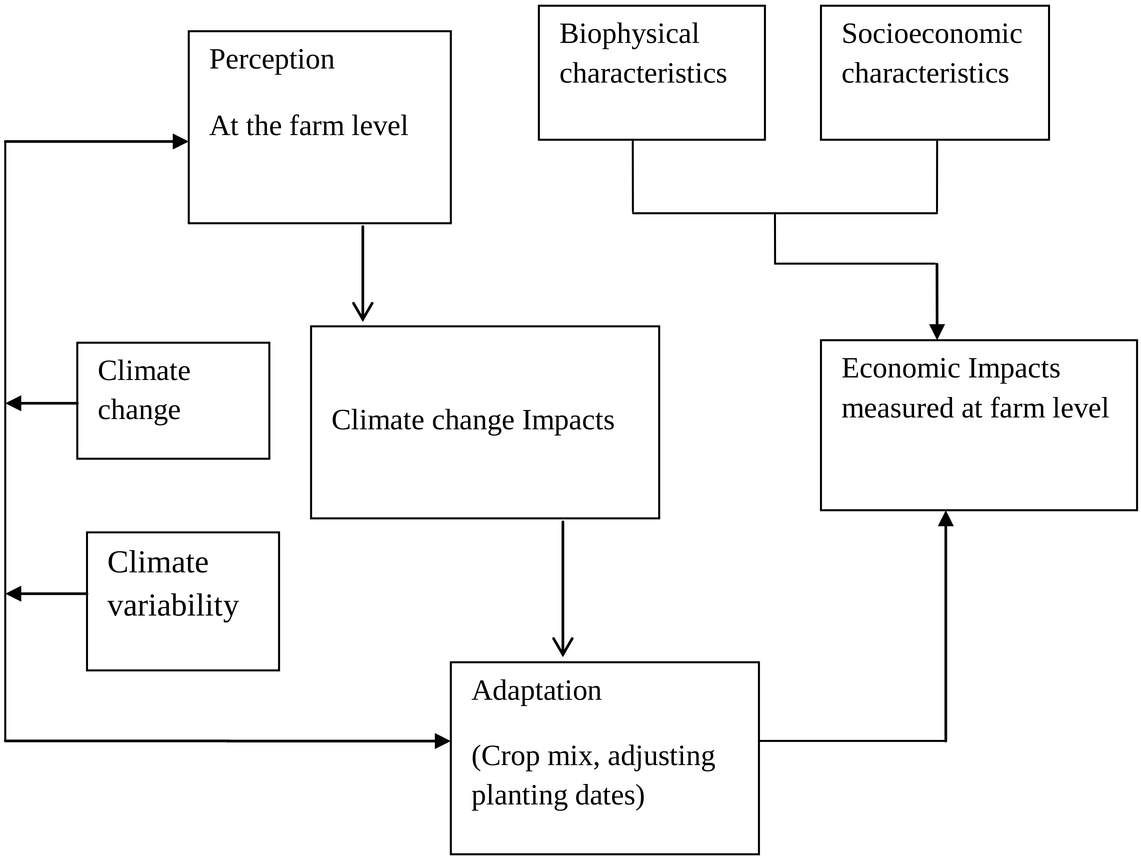

Figure 1: Conceptual framework of the study

3.2 Description of the Study Area

The study was conducted in the semi- arid and sub-humid areas of Tanzania whereby a total of eight regions were selected and from each region a district which is potential for maize production was chosen. The districts involved in this study were Kilosa, Chunya, Iramba, Hai, Handeni, Mufindi, Dodoma rural and Songea rural districts. The availability of downscaled rainfall and temperature data for over 30 years in the selected districts together with the variations in temperature and precipitation among them was also another factor for choosing the semi-arid and sub humid areas of Tanzania as a focus for this study.

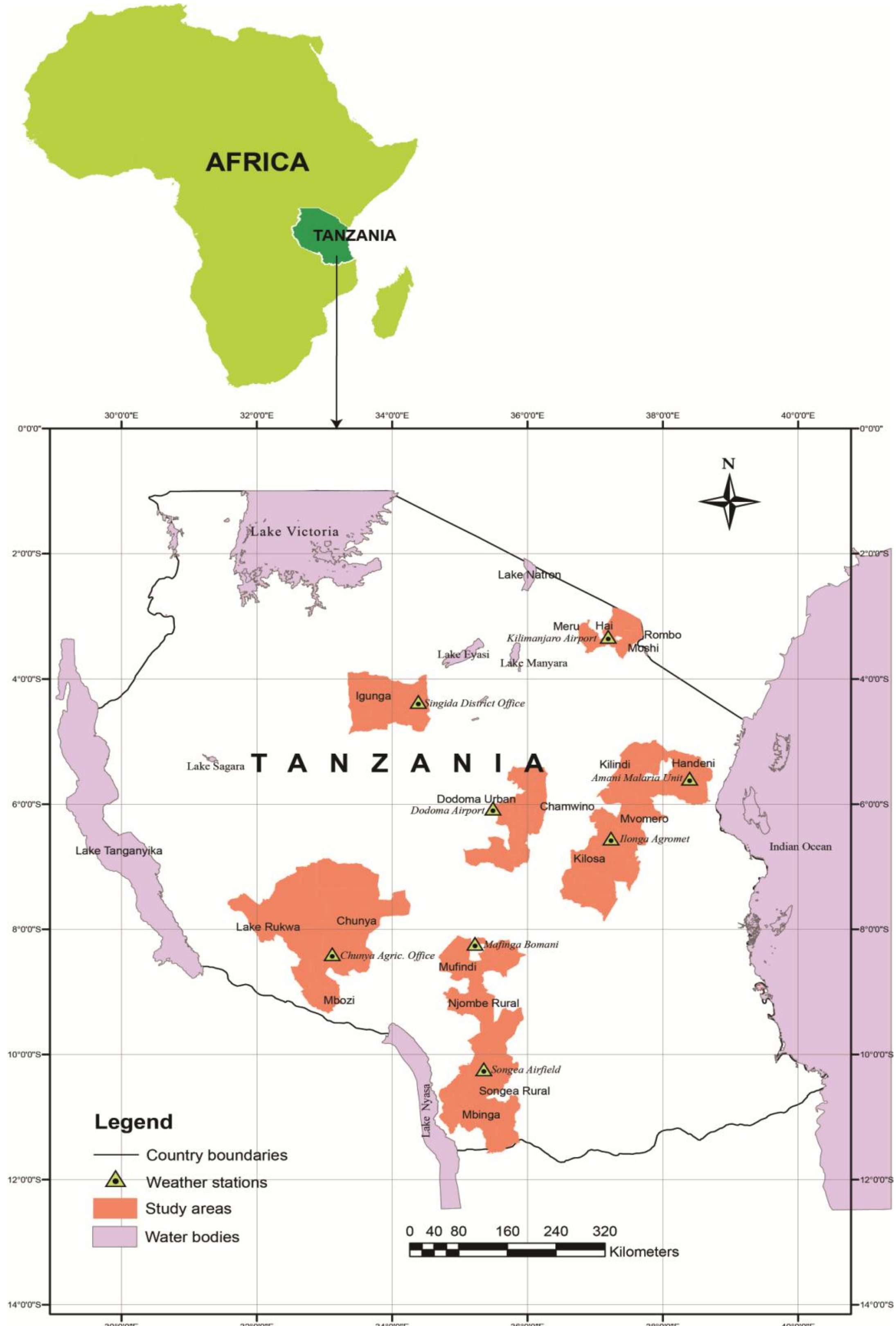

Figure 2: A map showing the study areas and representative weather stations

3.3 Research Design

The data which were used in this study originated from Tanzania National Panel Survey (NPS). The survey was carried out in 2011/12 whereby a formal survey instrument was prepared and trained enumerators collected the information from the sampled crop producing households in a face-to-face interview.

The survey collected information on several factors including household composition and characteristics, farmers welfare, food security, livestock ownership, area planted, production yield data for different crop types, health conditions of the households, household income sources, major consumption expenses, annual and permanent crops planted, farm implements and soil information.

Similarly the climate data over the 30 years were obtained from Tanzania Meteorological Agency. Theseincluded the daily rainfall as well as the maximum and minimum temperature for the selected districts which were collected from the meteorological station located near or within the districts.

In the survey a total sample of 323 farming household was covered. Out of this overall sample198 and 125 households who planted maize in the long rain season were selected from the sub-humid and semi-arid areas, respectively.323 respondents growing maize and located near the weather stations were selected because the sample size can give a precise picture of how climate change affects the farmer’s net revenue in the study areas.

3.4 Data Analysis

3.4.1 The empirical Ricardian framework

The empirical analysis began by estimating the response of net farm revenue to climatic variables, socio-economic and bio-physical variables. The response was examined according to zones by using the regional dummies. The first model examined the effects for the sub humid areas while the second model tested the effects for the semi-arid areas and the third model examined the response across all farms.

The specification of Ricardian model in this study assumed a quadratic relationship between net farm revenues and climatic variables to reflect the nonlinear relationship between net farm revenues and climatic variables that is consistent with other Ricardian studies applied elsewhere (Mendelsohn *et al.,* 1994, 1996; Kumar and Parikh, 1998; Sanghi, 1998; Sanghi *et al.,* 1998; Mendelsohn and Dinar, 1999, 2003). The quadratic terms reflected the response function of net revenue as a function of climate variables. The positive quadratic terms will indicate that net farm revenue function is U-shaped and negative quadratic terms will indicate the function is hill-shaped (Mendelsohn and Dinar, 2003). The expected relationship between net revenue and temperature based on agronomic research and past cross-sectional analyses is hill-shaped (Mendelsohn and Dinar, 2003). The suggestion from this prospect is that a negative relationship is expected, implying that further increase in temperature would have an adverse effects on net maize revenues and hence agriculture. In addition to this, the estimation assumed a linear relationship between net farm revenues and other variables (soil and socio-economic) that is also consistent with other Ricardian studies such as those mentioned above.

3.4.1.1 Analysis of the relationship of income from maize production with biophysical and socioeconomic variables

$Q_i = Q_i(K_i, E)$……………………………………………………………….............(1)

Where i= 1,2,3,4,…….., n.

$K_i = (K_{i1}, K_{i2}, \ldots\ldots K_{ij})$ is a vector of all inputs used in producing good i.

K_{ij} = are inputs used in producing good i, and j (1,2,3,…… j).

$E = (E_1, E_2, E_3, \ldots E_m, \ldots E_M)$ is a vector of areas specific exogenous environmental factors such as temperature, precipitation and soil which are common to the production area.

With a given set of factor prices wj, E and Q, the farmers cost minimization function will be presented as,

$C_i = C_i(Q_i, w, E)$……………………………………………………………...............(2)

Where,

Ci is the cost function of producing good i,

w $(w_1, w_2, w_3, \ldots\ldots$ wj) = vector of factor prices

With the given market price for good i, P_i the profit maximization function of a given producer is,

$Max\pi = P_i Q_i(K_i, E) - C_i(Q_i, w, E) - P_L L_i$…………………………………….............(3)

Where,

P_L is the annual cost or land rent,

L_i is the land under production of good i.

Under perfect competition all profits in excess of normal returns to all factors (rents) are driven to zero as below

$P_i Q_i * (K_i, E) - C_i\,(Q_i, w, E) - P_L L_i = 0$……………………………………………..(4)

If the production of good *i* is the best use of the land given E, the observed market rent on the land is equal to the annual net profits from the production of the good. Solving for

$P_L$from the equation (4) gives land rent per hectare to be equal to net revenue per hectare as follows,

$$P_L = (P_i Q_i *(K_i, E) - C_i *(Q_i *, w, E))/ L \text{ ....(5)}$$

Farm value (land value) reflects the present value of future net productivity captured by

$$v = \int PLEe^{\delta t} dt \text{..(6)}$$

$$V = [\sum P_i Q_i (K_{i,} E) - C_i (Q_i *, w, E)/ L_i]e^{\delta t} dt \text{ .... (7)}$$

Assuming a net revenue maximizing farmer who chooses K, given the characteristics of the farm and market prices, the Ricardian method is a reduced form model of the endogenous variables which are climate, soil variables and socioeconomic variables that affects farm value.

The standard Ricardian model can thus be presented as a nonlinear function where the net farm value per hectare is regressed against climate and other socioeconomic variables as shown below,

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + U \text{ ....(8)}$$

$$V = \beta_0 + \sum[\beta_1 T + \beta_2 T^2 + \beta_3 P + \beta_4 P^2] + \sum \mu_h Z_h + \phi G + \varepsilon \text{ ....(9)}$$

Where: F is a vector of climate variables (T for Temperature and P for precipitation), Z= vector of soil variables, G = vector of socioeconomic variables and U is an error term.

F (T and P) and F^2 (T^2 and P^2) capture linear and quadratic terms for temperature and rainfall. The introduction of quadratic terms for temperature and rainfall reflects the non-linear shape of the response function between net revenue and climate. From past studies one expects that farm revenue will have a U-shaped or hill-shaped relationship with temperature. When the quadratic term is positive, the net revenue function is U-shaped, but when the quadratic term is negative, the function is hill shaped. For each crop, there is known temperature where that crop grows best across the seasons, though the optimal temperature varies from crop to crop (Mendelsohn *et al*., 1994).

3.4.1.2 Determination of marginal impact of temperature and rainfall on income from maize production

From equation 8;

$$V = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + U$$

$$\mathrm{E}\left[\frac{dv}{df}\right] = \beta_1 + 2\beta_2 \mathrm{E}(F) \quad \text{...}(10)$$

To analyze the marginal impact of each climate variable, consider equation 9

$$V = \beta_0 + \sum\left[\beta_1 T + \beta_2 T^2 + \beta_3 P + \beta_4 P^2\right] + \sum \mu_h Z_h + \phi G + \varepsilon$$

$$\frac{\partial V}{\partial T} = V_i\left(\beta_1 + 2\beta_2 T\right) \quad \text{...}(11)$$

$$\frac{\partial V}{\partial P} = V_i\left(\beta_3 + 2\beta_4 P\right) \quad \text{...}(12)$$

The marginal impact of temperature and precipitation depends on the signs of $\beta_1 + 2\beta_2 T$ and $\beta_3 + 2\beta_4 P$ respectively.

3.4.1.3 Prediction of a range of potential future impacts on maize production under a mid-range emission scenario

Kurukulasuriya and Mendelsohn (2008) showed that one can analyze the impact of exogenous changes in environmental variables up on net economic welfare (ΔW). Hence, the net economic welfare is the change in welfare induced or caused by changing environment from a given state A to B, which causes environmental inputs to change from E_A to E_B.

$$\Delta W = \int_0^{Q_B} \left[P_i Q_i - C_i\left(Q_i, w, E_B\right)/ L\right] e^{\delta t} dQ - \int_0^{Q_A} \left[P_i Q_i - C_i\left(Q_i, w, E_A\right)/ L\right] e^{\delta t} dQ \quad \ldots\ldots\ldots\ldots\ldots\ldots..(13)$$

Mendelsohn *et al.,* (1994) assumed that market prices do not change as a result of the change in environmental variables (E), then by considering a constant vector price P= (p1,…,pi,….pn), equation (13) is reduced to

$$\Delta W = W\left(E_B\right) - W\left(E_A\right) = \left[PQ_B - \sum_{i=1}^{n} C_i\left(Q_i, w, E_B\right)\right] - \left[PQ_A - \sum_{i=1}^{n} C_i\left(Q_i, w, E_A\right)\right] \ldots\ldots\ldots\ldots(14)$$

From equation (4);

$$P_i Q_i * (K_i, E) - C_i(Q_i, w, E) - P_L L_i = 0$$

$$P_L L_i = P_i Q_i - C_i(Q_i, w, E) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15)$$

Substituting equation (15) into equation (14)

$$\Delta W = W\left(E_B\right) - W\left(E_A\right) = \sum_{i=1}^{n}\left(P_{LB} L_B - P_{LA} L_A\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

Where P_{LA} is the value per hectare of land area L_A in state A and P_{LB} is the value per hectare of land area L_B in state B. Consequently the present value of welfare change is;

$$\int_0^{\infty} \Delta W e^{\delta t} dt = \sum_{i=1}^{\infty}\left(V_B - V_A\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(17)$$

This is “the Ricardian estimate of the value of environmental change” by the definition of Ricardian model.

The impact of changing climate variables on net revenue from E_A to E_B is shown as

$$\Delta NR_i = NR_{(i,t)} - NR_{(i,t-1)}$$

$$NR_a = \sum_{1}^{n} \frac{NR}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(18)$$

Where;

NR_A is the average of the change in net revenue per hectare.

NR $_{(i, t)}$ and NR $_{(i, t-1)}$ are the forecasted values of the net revenue per hectare in period under new climate scenario and predicted values of net revenue per hectare of the base climate scenario respectively.

Equation 18 can be further expressed in terms of temperature and precipitation as

$$\Delta NR_i = NR_{(i,t)}(T_t, P_t) - NR_{(i,t-1)}(T_{t-1}, P_{t-1}) \qquad (19)$$

Where $T_t = T_{t-1} + \Delta T$ and $P_t = P_{t-1} + \Delta P$

$NR_{(i,t-1)}(T_{t-1}, P_{t-1})$ is the predicted value of maize net revenue per hectare with temperature and precipitation for the base climate scenario while $NR_{(i,t)}(T_t, P_t)$ is the change in crop net revenue per hectare of a given area with temperature and precipitation under the new climate scenario.

The average of change in net revenue per hectare gives the impact of a given climate change scenario (Deressa, 2007; Gbetibouo and Hassan, 2004; Kassahun, 2009).

3.5 Econometric Model Specification

In this study, to analyze the impact of climate change in maize production by using a Ricardian approach, the net farm revenue per hectare from maize production was used as a dependent variable against a set of independent variables which included the climate variables (temperature and precipitation), set of soil variables and vector for socioeconomic variables (farmer education, family size, access to credit and extension services, the health of the farmer). This is due to the fact that the Ricardian theory is consistent when net revenue is used instead of land value since land values are based on the discounted stream of future net revenues (Kurukulasuriya and Ajwad2006).

Therefore the modified Ricardian model adopted for this study depends on a set of climate and non-climate variables considered as drivers of adaptations.

$$NR_{ha} = \beta_0 + \beta_1 LGPTemp + \beta_2 LGPTemp^2 + \beta_3 LGP\Pr ec +$$
$$\beta_4 LGP\Pr ec^2 + \sum_{i=1}^{n} \alpha_i soil + \sum_{j=1}^{m} \mu G_j + \varepsilon_k$$

.............................(20)

Where; LGP *Temp* and LGP *Temp*^{2} are the linear and square mean long-term weather temperature for the length of growing period of maize. LGP *Prec* and LGP *Prec*^{2} is the mean long-term weather linear and square precipitation for the length of growing period. The variables G_j is a set of socioeconomic variables and geographical coordinates and the $\beta_1, \beta_2, \beta_3, \beta_4, \alpha_i$ and μ are coefficients for the linear and squared temperature and rainfall of growing period, soils and socioeconomic variables respectively and ε_k is the random disturbance term of the model.

3.6 Econometric Estimation

An econometric model is an important tool in separating and determining the influence of several explanatory variables on a dependent variable. Outliers, heteroscedasticity, multicollinearity and endogeneity of explanatory variables are major econometric problems often faced with cross-sectional data. In light of the fact that these econometric issues will likely affect the robustness of the regression results, the following remedies were undertaken prior to analyzing the econometric model.

For multicollinearity it is important not to include two independent variables in the model with variance inflation factor (VIF) greater than ten (Mela and Kopalle, 2002). In this study the climate variables and their squared terms were found to have potential multicollinearity between them and therefore to address this problem the climate variables were centered before computing the squared climate variables from themby subtractingthe mean of climate variables from every case making the mean of the centered climate variables equaling to zero while the standard deviation remained the same.

But again a two stage least square estimation method was used in analysing the parameters in the standard Ricardian model so as to correct for the problem of endogeneity of explanatory variables which is caused when the error term is correlated with one or more explanatory variables included in the model.This problem was solved by using an instrumental variable (IV) estimator which requires that there are valid instrumental variables that are highly correlated with the endogenous regressors but are not correlated with the error term.The standard Ricardian net revenue model to be estimatedis presented in equation (20) but the net revenue equation to be estimated and the identifying instruments are shown in equation (21) below:

$$Y = \alpha + bY_1 + cX_1 + X_2 + \mu \qquad \text{.......(21)}$$

X_1 = Age, Gender, Household size, Education, Access to credit, Distance to market, Livestock holding, loam, sandy, rainfall, rainfall square, temperature, temperature square

X_2= identifying instruments (farm size)

Y is dependent variable (i.e. Net revenue); Y_1 is a vector for a predictor variable that may or may not be endogenous (i.e. Household size); X_1 is a vector for exogenous variables; X_2 is a vector for exogenous variables excluded in equation (21).

This procedure does not change the standard Ricardian model but rather it corrects for the problem of endogeneity of explanatory variables.The Durbin χ^2 andWu-Hausman tests for endogeneity were used to test if the variables are endogenous and revealed that theendogeneity problem was removed since the Durbin χ^2 is 8.2461 (p = 0.0041) and the Wu-Hausman F statistic is8.06916 (p = 0.0048), indicating that the explanatory variables included in the model are exogenous.

3.7 Description of Dependent andExplanatoryVariables

3.7.1 Net maize revenue per hectare

The dependent variable: Net Revenue is measured as crop net revenue per hectare of cropland as opposed to per hectare of farmland, which would include farmland under livestock and other farming activities.

In this study net maize revenue per hectareis gross maize revenue (which is the product of total maize harvested and the price of maize) less the total variable cost of production. The total harvested maize includes the maize that was used for household consumption, maize sold and maize used as livestock feeds and the costs were mainly the total variable costs whereby in this studyit included fertilizer, pesticides, transportation, storage, seeds and labor costs. The household labor costs were excluded because of the possibility of overestimation of the costs whereby it was controlled by using household size in the model to show the impact of family labour in maize net revenue.

3.7.2 Climate variables: temperature and precipitation

The data for climate variables were obtained from Tanzania Meteorological Agency, since it is said that weather stations give accurate measures of ground conditions(Mendelsohn *et al.*,2004).The long-term computed mean values for temperature and rainfall were used to explain the long term plot level climate information for 30 years.

The long rain season (February to May) *masika*was used to represent the length of growing period for this study.The averages of each month for the period of 30 years were estimated and later they were added together and then divided by thirty years to get the long-term mean for temperature and rainfall. The computed quadratic terms for temperature and rainfall were also included in the model so as to capture the non-linear relationship between climate and maize production. In addition to that, further attempt was made to include the interaction term between the linear climate variables as agronomic literature suggested, however they were not statistically significant and therefore were removed from the model.

3.7.3 Socio-economic variables

The variables used in the model included the total land under maize cultivation, livestock ownership, access to credit, distance to market, age as a proxy for farming experience, household size as a proxy for household labor and education level of the household head.

i. Education of the household head

This is the number of years spent by the head of the household in acquiring education and for this study the expected sign is positive. Empirically, education has been proven to be related to early adopters and to greater productivity (Norris and Batie, 1987).

ii. Household size

Household size measured by the number of members in a household was used as a proxy for farm labor to assess the effect of labor availability on net farm revenue. Mano andNhemachena (2006) argue that large household size tend to divert part of its labor force into non farming activities but Hassan and Nhemachena (2008) challenge this viewbyarguing that the opportunity cost might be too low in most smallholder farming systems as off farm opportunities are difficult to find in most cases and revealed that household size show mixed impacts in many studies. Adult labor equivalent scale was not used in this study to show the contribution of each family member in the maize net revenue given the nature of data used which provided the age of the heads of the households only.

iii. Age of the household head

This is the number of years lived by the household head; it is said to represent experience in farming(Deressa *et al.*, 2010). The older the farmer, the more experienced he or she is in farming and the more he or she is exposed to past and present climatic conditions. This is evident in Gbetibouo (2009) whofound a positive relationship between the age of the household head and net revenue. Therefore in this study this variable is expected to takepositive sign.

iv. Access to credit

Access to credit easies the financial constraints faced by farmers. When having an access to credits farmers will be in a position to finance adoption of new technologies such as oxen, improved crop variety seeds and fertilizer. Findings by Gbetibouo (2009) and Deressa *et al.*(2009) show that access to credit significantly influences the farmer to adapt to climate change and increase his/her net revenue.

v. Farm size

This is the total landholding of farming household. In this study it was measured in terms of hectares of land that were only planted with maize crop and the bigger the farm size, the more likely the farmer is to adopt suitable strategies to cope with climate change.

vi. Livestock holding

The livestock variable was included to assess the importance of livestock in helping farmers to adapt to the changing climatic conditions and as well as to observe if there is any competition that exists between maize cultivation and livestock keeping. The underlying assumption was that further increase in temperature and reduction in rainfall were less favorable for crop production and thus livestock keepingwas an important option under very stressful conditions.

3.7.4 Soil variables

There is variability in soil types across districts in Tanzania.The texture of the soil was considered as a classification of the soil type and for each plot farmers were asked for their plots' soil texture accordingly.Three soil textures where available in the data set. These soils included loam, sand and clay soils whereby the expected effect of the soils texture will depend on the type of the soil.

Table 1: Description of variables used in the model and prior expectation

Climate Variables	**Type of variable**	**Sign**	**Description of the expected relationship with dependent variable**
Temperature	Continuous	+/-	Temperature influences net revenue positively or negatively
Temperature Square	Continuous	+/-	Temperature influences net revenue positively or negatively
Rainfall	Continuous	+/-	Rainfall influences net revenue positively or negatively
Rainfall Square	Continuous	+/-	Rainfall influences net revenue positively or negatively
Socio-economic variables			
Age	Continuous	+/-	Age of household head either positively or negatively influences net revenue from maize production
Family size	Continuous	+	Number of individuals in the household
Education	Categorical	+	The educational level of the head of household represented by years of schooling
Access to credit	Dummy	+	Getting credit services is expected to positively influence farmers' net revenue.
Farm size	Continuous	+	A larger land holding is expected to positively influence adoption.
Distance from farm to market	Continuous	+	It is expected that the closer the input or output market is, the higher the chance to increase net revenue.
Livestock holding	Dummy	+/-	Livestock holding is expected to influence positively or negatively net revenue
Soil Variables			
Loam	Dummy	+	Loam soil type, takes the value 1 if the soil is loam type in texture, and 0 otherwise.
Sandy	Dummy	+/-	Sandy soil type, takes the value 1 if the soil is sandy type in texture, and 0 otherwise.
Clay	Dummy	-	Clay soil type, takes the value 1 if the soil is clay type in texture, and 0 otherwise.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Demographic and Socio-Economic Characteristics of the Sample Households

The sampled households varied in terms of socioeconomic and demographic characteristics. The socio-economic characteristics examined were age, family size, farm size and education level of the household head as they are important indicators of individual behaviors for this study.

Table 2: Descriptive statistics for the socio economic andsoilvariables

Variable	Mean	Standard Deviation
Age	48.31	15.26
Household size	5.82	2.79
Education	12.68	8.11
Farm size (hacter)	2.45	3.13
Livestock	1.03	0.17
Distance to market (Km)	16.65	20.45
Access to credit	1.99	0.11
Rainfall (mm)	0.67	0.69
Temperature (^{0}C)	2.39	0.51

4.1.1 Age of the household head

The sampled household heads were on average 48 years old (Table 2) indicating that most were falling in the economically productive population in Tanzania which ranges between 15 to 64 years of age (NBS, 2013). In additionthe age of the household head can be used to capture farming experience of the respondents since as shown by Maddison (2006) and Nhemachena and Hassan(2007) that there is a positive relationship between age of the head of the household and the chance of acceptance of adaptation measures to climate change.

4.1.2 Education level

Farmers were found to have attended school for about 12.68 years. Higher level of education is believed to be associated with access to information on improved technologies and higher productivity (Norris and Batie, 1987). Therefore farmers who are more educated are expected to adapt well to climate change.

4.1.3 Family size

Furthermore Table 2 shows that the average family size in the study area was 5.82 persons per household which is above the national average size of 4.8 persons per household (NBS, 2013). It is assumed that biggerfamily size is associated with higher labor endowment, which would enable households to undertake various agricultural activities.

4.1.4 Farm size

Again the area under cultivation showed that on average a household cultivate 2.45 acres of land which is slightly above the average utilized area for cropping activities per agricultural household in Tanzania which is 2.0 acres of land (NBS, 2013).

4.2 Results of Regression Analysis

4.2.1 Validation of the model

The Ricardian model was used to estimate the impact of climate change on maize net revenue and the results are presented in Tables 3, 4 and 5. An additional insight for policy design was added by analysing the marginal effects, which were calculated as the partial derivate of the non-linear function.

Themodels yielded the best statistical fit for the data in the regression analysis. They demonstrated a good fit at 1% level of significance that was observed from χ^2 statistic and the coefficient of determination (R^2) for the model explained about19.89 %across all farms,18.16% in the semi-arid areas and 19.10% the sub humid areas of the variations in net revenues per acre from maize production, and respectively.The extent in which the model explains the variations in net revenue from maize production is consistent with other studies done elsewhere and employed a Ricardian model (Mano and Nhemachena, 2007; Thapa and Joshi, 2010; Kurukulasuriya and Mendelsohn,2008; Benhin, 2006; Sene*et al.*, 2006).Furthermore the coefficient of determination suggested that farms vary from small scale to large commercial farms, a large part of the variations in net maize revenue remain unexplained by the variables taken into account (Kurukulasuriya and Mendelsohn, 2006).

4.3 Relationship between Net Revenue from Maize Production with the Predictor Variables

4.3.1 Model estimation results for sub humid areas

The relationship between climate and net farm returns can either be positive or negative depending on the crop and location (Lobell *et al*., 2011). In this study, the effect of quadratic seasonal climate variables on maize net revenue was not simply determined by looking at the coefficients since both the linear and the squared terms play a role (Kurukulasuriya and Mendelsohn, 2008). What was determined from the sign of the quadratic term is whether the relationship with net farm revenue is hill-shaped or U-shaped if the sign is positive or negative, respectively. Table 3 shows that both linear terms for rainfall and temperature for the sub-humid areas were not significant and had a negative relationship with net revenue from maize due to the already existing high levels of rainfall and any further increase in rainfall will results into decrease in production and consequently decrease in net revenue from maize production.

Table 3: Parameter estimates of Ricardian maize model for sub humid areas

Net revenue	Coefficient.	Z
Household size	(Instrumented)42576.17	0.96
Farm size (Hacters)	Instrument	
Education	335.0325	0.25
Loam	139004.2	5.16***
Sandy	20136.05	0.50
Clay (reference group)		
Livestock	-14514.31	-0.24
Distance to market (km)	-479.6837	-1.03
Access to credit	45517.62	0.46
Rainfall (mm)	-2432158	-0.42
Rainfall square	434853.2	0.35
Temperature (^{o}C)	-1779928	-0.42
Temperature square	27500	0.43
Region code	0	
Constant	4388693	0.40
Number of observation	198	
Wald chi2(11)	78.33	
Prob>chi2	0.0000	
R-square	0.1910	

Note: *** Significant at 1% level

In this study the relationship between loam soil and net revenue from maize production was significant at 1% level in the sub-humid areas. The direction of the relationship between loam soil and net maize revenue was positivewhich is explained by the fertility level and water retention capacity of the soil. But again in relation to the socio-economic variables none of them had a significant importance in explaining net revenue from maize production in the sub humid areas. Access to credit, household sizes, education of the household head, were found to have a positive relationship with maize net revenue in the sub humid areas implying that farmers who received credit had large household sizes and household heads who attended schoolincrease their farm net revenue.

4.3.2 Model estimation results for semi-arid areas

Semi-arid regions are the most vulnerable regions to climate change since higher temperatures and reduction in rainfall and increase in rainfall variability could have substantially negative impacts (Antle, 2009). From Table 4, the relationship between net farm returns and climate variables is negative with temperature having a significant relationship with maize net revenue at 5% level of significance. On the other hand the rainfall variable is not significant. The negative signs suggest that when rainfall and temperature increase net revenue decreases until a certain point where any further increase in rainfall and temperature results into an increase in net revenue in the semi-arid areas.

Of all the socio-economic variables specified in the model; the house holdsize and education of the household head were the only variables found to be significant in explaining net revenue from maize productionat 1% level. Other variables such as livestock, access to credit and distance to market were not significant implying that they do not impact maize net revenue in the semi-arid areas.

As expected, education of the household head, measured in terms of number of years spent in school had a positive relationship with net revenue from maize production showing that education is associated with improved farming information that is important for agricultural productivity and in speeding up the adoption of new technologies.Household size was found to have a positive relationship with maize net revenue. This result denotes that households' net revenue increased with the size of household.

Access to credit, distance to market and livestock keeping were not significant factors influencing maize net revenue. Distance from the farm to the market (either input or output market) as a result of the costs that farmers incur in terms of money and time as the market places becomes further from their farm plots. Similar results were found by Kassahun (2009) who found a negative relationship between net farm revenue and distance from input market.Sandy soil influenced maize revenue significantly at 5% level in the semi-arid areas. But despite being important in determining maize net revenue, the sandy soil had a negative relationship with net revenue from maize production.

Table 4: Parameter estimates of Ricardian maize model for semi-arid areas

Net revenue	**Coefficient**	**Z**
Household size	(Instrumented)32157.14	3.33***
Farm size (Hacters)	Instrument	
Education	4782.223	3.13***
Loam	34017.98	0.78
Sandy	-83184.6	-2.01**
Clay (reference group)		
Livestock	-3419.732	-0.05
Distance to market (km)	-821.0523	-0.98
Access to credit	-1966.218	-0.02
Rainfall (mm)	-646562	-1.04
Rainfall Square	-586404.6	-0.69
Temperature (^{o}C)	-76890.58	-2.07**
Temperature Square	0	
Region code	0	
Constant	400292.9	0.89
Number of observation	125	
Wald chi2(10)	75.48	
Prob>chi2	0.0000	
R-squared	0.1816	

Note: *** Significant at 1% level ** Significant at 5% level * Significant at 10% level

4.3.3 Model estimation results across all farms

Rainfall and temperature had no significant importance in determining net farm revenue from maize production (Table 5). Rainfall was found to have a positive relationship with maize net revenue showing the importance of rainfall in maize production while temperature was found to have negative or a U-shaped relationship with maize net revenue implying that as temperature increases net revenue will decrease until a certain point then any increase in temperature will results into increase in net revenue.

Table 5: Parameter estimates of Ricardian maize model for all farms

Net revenue	**Coefficient**	**Z**
Household size	(Instrumented) 34654.28	3.67***
Farm size (Hacters)	Instrument	
Education	2069.117	2.30**
Loam	97428.81	4.38***
Sandy	-13125.76	-0.58
Clay (reference group)		
Livestock	-4925.528	-0.12
Distance to market (km)	-503.449	-1.30
Access to credit	20045.63	0.32
Rainfall (mm)	1382.528	0.02
Rainfall Square	-20791.45	-0.32
Temperature (^{o}C)	-17275.58	-0.52
Temperature Square	-59621.57	-1.74*
Region code	3655.517	0.15
Constant	-118212.8	-0.75
Number of observation	323	
Wald chi2(12)	153.88	
Prob>chi2	0.000	
R-squared	0.1989	

Note: *** Significant at 1% level ** Significant at 5% level * Significant at 10% level

Among the socio-economic variables; householdsize significant at 1%level, education of the household head significant at 10%level were the only socio-economic variables found to be statistically significant in explaining net revenue from maize production across all farms (Table 5),and other variables such as livestock, access to credit and distance to market were not significant at any required level in the model indicating no impact of these variables on maize net revenue across all farms.

Education of the household head measured in terms of number of years spent in school which was important in explaining net revenue from maize production across all farms had a positive relationship with net revenue from maize production.In line with other studies, education is seen as a tool to enhance farm productivity directly by improving the quality of labor, increasing the ability to adjust to imbalances and through its effects upon the propensity to successfully adopt innovations and therefore it is thought to be most important to farm production in a rapidly changing technological and economic environment (Shultz, 1975).

Household size was found to have a positive relationship with maize net revenue. Access to credit, distance to market and livestock keeping were not significant in explain maize net revenue. Access to credit which was also not significant was found to have a positive relationship with maize net revenue across all farms implying that farmers who receive credit increase their farm net revenue.

With regard to the soil variables, the relationship between loam soil and net revenue from maize production was significant at 1% level across all farms and had a positive relationship with maize net revenue implying its importance in determining maize net revenue.The sandy soil was not significant at any required level but was found to have a negative relationship with maize net revenue across all farms.

The direction of the relationship between loam soil and net maize revenue was positive. The positive relationship of the loam soils is explained by the fertility level and water retention capacity of the soil. Loam soil is usually more fertile and provides a good medium for maize production and thus support maize productivity. This shows the importance of controlling for soil types as it brings out more strongly spatial differential impacts on net farm revenues across different agro-ecological zones (Mano and Nhemachena, 2006).

4.4 Marginal Impact Analysis

The results from the Ricardian analysis only show the impact of climate variables (temperature and rainfall) as just increasing or decreasing the farmers' net revenue.Therefore, in order to measure the magnitude of the impact of the climate variables on net revenue the marginal effects of temperature and rainfall for the sub humid and semi-arid areas and across all farms are computed using the results from the regression analysis in Table 3, 4 and 5 respectively. It is important to estimate the marginal impacts of temperature and rainfall since policy makers use them in designing various policies for agricultural development (Tol, 2009). In this study the marginal effectsof rainfall and temperature were estimated in order to observe the effect of small changes in temperature and rainfall on maize net revenues. The marginal effects of climate variable were evaluated at their mean whereby they represent the change in net revenue per hectare of maize produced per °C or mm/year for the sub humid and semi-arid areas of Tanzania.

In Table 6, the marginal climate impacts for the sub-humid areas were calculated using the results in Table 3 whereby the marginal climate impacts were found to be negative for both climate variables with rainfall having a bigger impact compared to temperature. The reason for this being the existence of large volume of rainfall and any further increase in rainfall will result into decrease in maize production due to the already existing high levels of water and moisture into the soils in these areas. In this study net revenue was estimated to decrease by Tshs 1 692 907.56 when rainfall increase by 1mm while an increase in temperature by 1^{o}C will results into decrease in net revenue by Tshs 1 651 778 in the sub-humid areas.

Table 6: Marginal climate impacts on maize net revenue (Tshs)

Variable	**Marginal Climate Impact**	**F-statistics**
	Sub-humid	
Rainfall	-1 692 907.56	5.499**
Temperature	-1 651 778	22 102.8**
	Semi-arid	
Rainfall	-1 092 229.5	44.2**
Temperature	-76 890.58	-
	Across all farms	
Rainfall	-26 478.01	0.847
Temperature	-302 207.06	-24.69**

Note: ** significant at 5% level

But again the marginal climate impacts calculated using results in Table 4 for the semi-arid areas estimated net revenue to decrease by Tshs 1 092 229.5 when rainfall increases by 1mm and an increase in temperature had no any significant impact on maize revenue due to the omission of squared temperature variable as a result of co linearity with the temperature variable in the model.Furthermore, the marginal impacts for rainfall and temperature estimated using results from Table 5 were both negative for temperature and rainfall. These results indicatethat increase in rainfall and temperature is harmful for maize productivity.

The net revenue was estimated to decrease by Tshs 302 207.06 when temperature increases by 1^{o}C where by the reason for this relationship is that the greater than normal warming condition along with more water evaporation due to higher temperature which takes available water out of reach of maize plants can cause heat stress on maize and reduce the crop productivity. But again this result cannot be interpreted explicitly as net revenue reflecting changes in maize productivity since there are other factors that might affect maize net revenue such as prices, farm technology, limited access and availability of improved seeds.

But again with regards to rainfall the net revenue is estimated to decrease by Tshs 26 478.01 when rainfall increases by 1mm where by the reason for this relationship is due to the already existing high levels of rainfall in the country during the long rain season therefore increasing rainfall any further results in to flooding and damage of the maize crop.

4.5 Impact of Forecasted Future Climate Scenarios on Maize Net Revenue

In this section climate change scenario for the year 2050 were projected to evaluate climate change impact on maize net revenue in the future. This projection is an attempt to describe what would happen, given climate change. The regression coefficients have been used to evaluate the range of potential effects of climate change on the economics of the sub-humid and semi-arid areas agriculture.According to Amiraslany (2010)reported thatto accomplish the simulations, each temperature variable in the base model need to be increased to make new temperature variables reflecting different future climate scenarios, and in the same manner precipitation variables are multiplied by percentage change in future precipitation to calculate new precipitation variables reflecting climate change scenario. These new variables now have been adjusted to meet new climate conditions in the future. The impact of climate change is therefore given by the change in maize net revenue resulting from climate change.

In this study, the projection for the future climate scenario was basedon the study done by Wambura *et al.* (2014) on the climate change projections for Tanzania basing on the Coupled Model Inter-comparison Project Phase 5 (CMIP5)using the Mid-Century Representative Concentration Pathway (RCP) 8.5. The study projected an increase in rainfall by 18% which is equivalent to 189 mm of rainfall by 2050 but also it projected an increase in temperature by between 0.7^{o}C and 1^{o}C by the year 2050. These projections by CMIP5 were used to adjust the climate variables for this study to see the impact of the future increase in rainfall and temperature on maize net revenue for the sub humid and semi-arid areas of Tanzania.

This study estimated the impact of the projected future climate scenario on maize production system using the results from the estimated coefficients for net revenue function, under the assumption that the variable subjected to change was climate while all other factors remained constant. The estimation reflected the variation in net maize revenue per hectare for each farm.Table 7 presents the magnitude of the projected change in temperature and rainfall variables for a mid-range emission scenario which were used to adjust the climate variables for this study whose impacts are presented in Table 8.

Table 7: Baseline and future climate scenarios

Climate	**Temperature** (^{0}C)	**Rainfall (mm)**
Baseline	22.8	1069
Prediction	23.8	1258
Scenario (Change)	+1.0	+18%

Source: CMIP5 Climate Change Projections for Tanzania

The results presented in Table 8 show that there is a decrease in net revenue form maize production in the future when temperature and rainfall increases. The results indicate that climate change damages will continue to increase in the future which calls the need for adaptation measures to overcome such negative changes due to increase in temperature and rainfall or otherwise the impact will get worse in the future.

Table 8: Impact of changing rainfall and temperature on maize net revenue in the sub-humid and semi-arid areas of Tanzania

Item	NR/ha(Tshs)
Change in NR/ha due to change in rainfall	12 657.81
Change in NR/ha due to change in temperature	74 065.83
Net changes in NR/ha	14 759.17

Source: own computation from the model basing on the climate variables in Table 7

Basing on the projections given in Table 7, farmers are expected to experience a decrease in net revenue by Tshs 12 657.81per hectare when rainfall increases by 18% in 2050 in the semi-arid and sub humid areas of Tanzania. Also with respect to temperature a loss of Tshs 74 065.83per hectare in maize net revenue is expected when temperature increases by 1 ^oC in 2050.

In general, the magnitude estimated for future losses in net revenue from maize productioncalls for the need of having necessary interventions to reduce the future impact of climate change on maize production.Farmers in the study regions should be obliged to adjust their cropping calendar so as to cope with climate change. The result from Table 8 are in line with other studies (Hassan and Nhemachena, 2008; Kurukulasuriya and Mendelsohn, 2008; Gbetibouo and Hassan, 2004; Deressa and Hassan, 2009; Molla, 2009) which concluded an increase in temperature to be damaging to maize production.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The present study evaluated the potential impact of climate change on maize production in the sub-humid and semi-arid areas of Tanzania. A cross-sectional data collected from randomly selected 323 household by NPS in 2011/12 was used.The Ricardian approach was employed to quantify the economic damage to agriculture resulting from changes in climate with the advantage of taking into account various adaptation measures that farmers undertake to cope with climate change.

In this study farmers were assumed to be aware of the impact of climate change on maize production and therefore the central point of this study was to examine the relationship between climate variables and net revenue from maize production while controlling for the effects of the socio-economic and the bio-physical variables. The regression analysis was done separately for the sub-humid and the semi-arid areas and across all farmsfor the households that produce maize.

The results for Ricardian regression analysis using the two-stage least square estimation method across all farms showed a significant relationship between net revenue and household size, education and loam soil. With the exception of the squared temperature variable all climate variables were not significantly influencing net revenue. Therefore the presence of significantrelationship between net revenue from maize production with the socio-economic and soil variables shows their importance in determining farmers’ income from maize production.

The projections ofmarginal change in rainfall and temperature showed a net loss of Tshs 26478.01 and 302207.06 respectively from maize production per year in the study area.This indicates the need for more adaptation strategies such as changing of planting and harvesting dates, using improved maize varieties and irrigation system to be undertaken by farmers in order to cope with the likely changes in rainfall and temperature patterns in the coming years.

The study further examined the impact of future climate change scenario to see how maize production in the sub humid and semi-arid areas will respond to climate change. The benchmark for future levels of mid-century (2050) for climate variable from CMIP5 were used whereby the results showed that there will be a decrease in net revenue from maize production with an increase in temperature. But the results further indicated an increase in net revenue as rainfall increases though the increase is minor compared to the decrease resulting from increase in temperature.

The prediction shows an increase in the impacts associated with changes in long term temperature and rainfall whereby they will have a considerable impact on net revenue from maize production. Therefore, it is important for the government, research units and private sectors to invest resources in training farmers and supporting them against further adverse climatic conditions.

5.2 Recommendations

In view of the major findings and conclusions, the following recommendations are drawn:

i. In order to reduce the impact of increasing temperature and rainfall on maize net revenue, investing in technologies such as irrigation, planting of drought tolerant maize crop varieties is an important adaptation strategy that would help farmers to avoid the impacts that are associated with climate change in the future.

ii. The key policy message from this study is the need for the government through the meteorological department, research and extension and private sector to provide adequate information services to ensure that farmers are well informed about rainfall patterns in the coming seasons so as toenable them to make decisions about their planting dates.

iii. Another important policy message is that the government and private sectors together can help farmers to improve net farm revenues for by ensuring increased farmers' training, access to credit and extension services.

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